STRATEGIC INFRASTRUCTURE ASSET MANAGEMENT MODELING

Marie T. Harnly, Department of Systems and Engineering Management, Air Force Institute of Technology, 2950 Hobson Way, Wright-Patterson Air Force Base, OH 45443, 937-255-6565, marie.harnly@afit.edu

William E. Sitzabee, Ph.D., P.E., Department of Systems and Engineering Management, Air Force Institute of Technology, 2950 Hobson Way, Wright-Patterson Air Force Base, OH 45443, 937-255-6565, william.sitzabee@afit.edu

ABSTRACT

Effective asset management requires an overarching model that establishes a framework for decision-makers. A model also provides guidance for asset management business principles and illustrates the relationships among the components of asset management. This paper presents a strategic level asset management model that is applicable to agencies with a large infrastructure inventory and limited resources. This model highlights how the components tie together and influence each other to provide a holistic perspective of asset management. Decision-makers can use this model to make decisions that tie policies, infrastructure inventory, condition state, and budget constraints to system performance. Asset management of Air Force infrastructure provides an example of applicability for this model that aligns with the Next Generation Information Technology initiatives. The Air Force asset management example is weaved throughout the research project to demonstrate the utility of the model. As a result, insight is gained on ways to maximize efficiency and optimize the performance of infrastructure.

INTRODUCTION

Budget constraints and scarce resources have sparked agencies to maximize efficiency when operating and maintaining aging infrastructure. For example, the United States Air Force currently manages 139,556 infrastructure assets (facilities, runways, utility lines, and roadways) valued at 263.43 billion dollars [7]. In order to optimize the performance of these infrastructure assets, the Air Force (AF) Civil Engineer (CE) career field introduced a formalized approach for maintaining infrastructure and labeled this approach asset management [8]. Asset management, the foundation of the CE transformation which began in 2007, involves business practices that emphasize management techniques to focus and maximize limited resources [4]. The purpose of asset management is to meet a required level of service in the most cost effective manner while adhering to established goals and policies as well as remaining within budget constraints [14].

Along with introducing asset management, AF senior leadership restructured CE organizations at all levels during the CE transformation [4]. The incorporation of asset management functions at all vertical organizational levels (unit level, major command level, and headquarters level) created an emphasis on planning and implementing asset management principles in daily decision-making. Although the asset management culture is present throughout all levels of the corporate structure of CE organizations, there is an absence of a comprehensive framework to provide guidance for asset management business principles, which results in deficient project management tools for decision-making. As such, a requirement exists for a strategic level model. This strategic level model should illustrate the relationships among the components of asset management and integrate these components into a useful, decision-making tool in order to optimize the performance of infrastructure [18].

INFRASTRUCTURE CHALLENGES

Four challenges sparked the requirement for a strategic level model: financial factors as opposed to technical factors, short term planning as opposed to long term planning, network as opposed to individual projects, and allocating resources across asset types [3]. The financial factors, such as cost of maintenance and repair projects, are weighed against technical factors when implementing a solution. This constant challenge is exacerbated by a shrinking budget and by the monetary cost of necessary projects exceeding the funds available for these projects. Under these circumstances, "asset managers must allocate funds among competing, yet deserving requirements" [23, p. 4].

Short term remedies are evaluated against long term goals. A short term fix may not be the most economical solution and a long term strategy may not be the timeliest solution [4]. The difficulty in balancing short and long term factors significantly increases with rapidly changing targets and goals. These challenges hinder the ability to assess and delineate short term and long term budgets and priorities, creating an increasingly difficult task.

Additionally, infrastructure is an integrated system with individual components that function independently and in conjunction with other systems [24]. The interconnectedness of infrastructure links assets into a complex system of interrelated elements [17]. This concept of infrastructure coupling correlates the state of one infrastructure asset to the state of another, which creates an interdependency between the two [7]; however, most maintenance management systems (MMS) assess only individual components or isolated projects, instead of accounting for network goals and coupling effects. These individual projects are weighed against networks in which infrastructure is constrained by the weakest link or networks where parts should be replaced simultaneously in neighboring systems.

Last, budget constraints for maintenance and repair projects require decision-makers to allocate resources across asset types while considering the value an asset has to an agency's operations and the current condition of the infrastructure. The difficulty in allocating resources across numerous types of infrastructure assets is driven by the issue of objectively comparing the worth and importance of infrastructure assets. Rapidly changing leadership and goals along with these issues create an increasingly challenging task, to delineate among assets and determine which most require resource allocation. The contending factors of financial as opposed to technical, short term planning as opposed to long term planning, network as opposed to individual projects, and allocating resources across asset types provide challenges and opportunities for decision-makers. Agencies with a large, varying infrastructure set and limited resources require a strategic asset management model that properly balances these infrastructure challenges by creating a useful decision support system to guide the analytical process of asset management.

DATA MODELING PROCESS

Longley et al.'s data modeling process was used to create a logical asset management model that incorporates the components of asset management [13]. This method of data modeling is a type of systems modeling that defines and analyzes data requirements to support the business practices of an agency [2]. Specifically, "a data model is a set of constructs for representing objects and processes in digital form" [13, p. 178-179]. A data model also involves ontologies, which define the components of a system and associate them in classes, relationships, or functions [11]. Data modeling consists of four levels (listed in order of increasing abstraction): reality model, conceptual model, logical model, and physical model [13].

Data modeling is particularly applicable to projects that require management of data as a resource, integration of information systems, and modification of databases for organizational operations [25].

Specifically for the scope of this research project, data modeling focused on asset management processes for agencies with large infrastructure sets and the data required to make decisions based upon the strategic components of these infrastructure systems. The result of this data modeling process, in the context of the Air Force, will align with the Next Generation Information Technology Program Management Plan objective to streamline the required data and its transparency. Thus, this paper presents a logical model for strategic level asset management that followed the first three phases of the data modeling process.

Logical Model

Development of the logical asset management model produced a strategic level model of an operational infrastructure system. This logical model consists of components, defined and described in the reality model and conceptual model phases, that are prevalent to the business practices of asset management. The model was submitted for publication and graphically depicts influential strategic components as well as their relationships that are vital to the asset management process [21]. It also illustrates the ontologies and associations among the asset management components and identifies the data required to promote analysis of infrastructure operations. The unpublished work presents the general logical asset management model and provides an understanding of the strategic components depicted in the model as well as the relationships among these components.

The logical asset management model creates a comprehensive framework that provides guidance for the asset management process. It serves as a useful, decision-making tool that is applicable to agencies with a large infrastructure inventory and limited resources. This model enables decision-makers to formulate viable approaches and alternatives to infrastructure management and facilitates efficient use of the annual operations and maintenance budget in order to optimize the performance of infrastructure assets.

This paper used a representative sample of Air Force infrastructure to tailor the general logical model specifically to infrastructure operations of the Air Force [21]. Figure 1 presents the logical model validation, which modifies the general logical model to the Air Force's asset management process, depicts the components as they pertain to this specific organization, incorporates the Air Force entities prevalent to each component, and identifies the data required for analysis of its infrastructure systems. It also illustrates the importance of transparent data as well as streamlined data collection and maintenance, which Next Generation Information Technology aims to achieve for the Air Force [22]. In essence, the logical Air Force asset management model, presented in Figure 1, creates a decision-making framework for the Air Force that guides the analytical process of asset management and addresses infrastructure challenges, specifically for this organization.

The strategic asset management components illustrated in the logical model comprise the process of asset management for the Air Force.

Strategic Vision (*Air Force)* - Articulation and implementation of the strategic vision occurs both horizontally and vertically throughout the organization. Knowledge of the desired end state allows decision-makers to prudently dedicate resources to the operation, maintenance, and repair of infrastructure assets. Department of Defense (DoD) strategic level documents provide overarching guidance that the Air Force implements through its own strategic vision and operations. According to the strategic vision of the Air Force Civil Engineer, civil engineers seek to "provide sustainable installations by using transformational business practices" [16, p. 1]. This strategic vision highlights the use of asset management principles in daily operations and currently guides data collection, budgets, policies, and goals for the Air Force.

Inventory (*Air Force)* - The Air Force owns an incredibly diverse set of constructed facilities ranging from dormitories to aircraft hangars to warehouses [15]. These facilities support a myriad of government functions and are located on various continents. The age of the 139,556 infrastructure assets in the Air Force's inventory spans decades, and sometimes centuries, of building design and construction technologies [7]. The Air Force collects and maintains data for its infrastructure inventory and condition state of infrastructure in order to generate a snapshot of its assets; however considerable information technology (IT) issues exist because current data management systems do not effectively communicate with each other and data is entered multiple times into multiple data management systems [22]. As a result, individuals develop and maintain spreadsheets and databases of their own to compensate for inadequate systems.

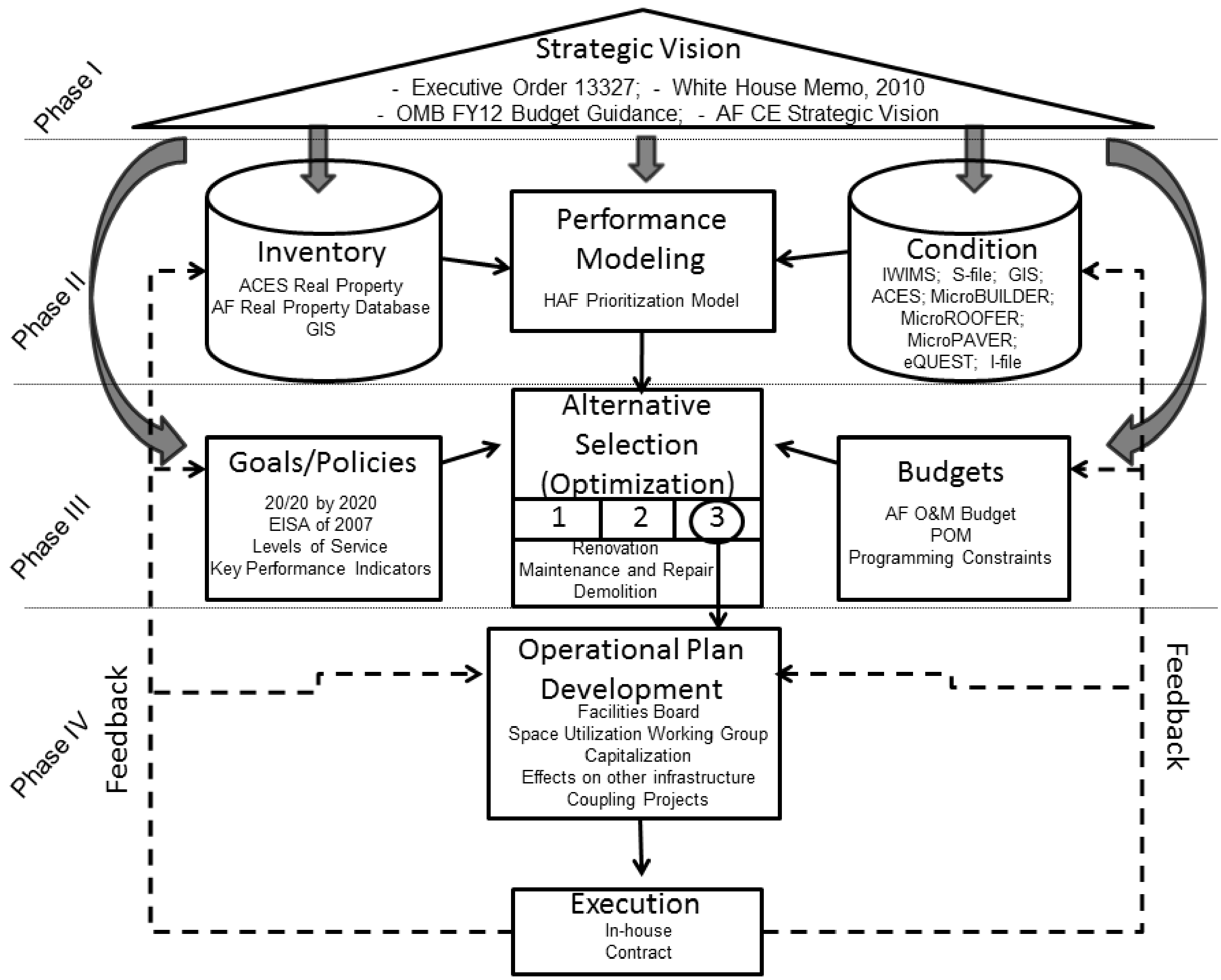

FIGURE 1. Logical Air Force Asset Management Model

Condition (*Air Force)* - The Air Force collects condition state data in a maintenance management system (MMS), called the Interim Work Information Management System (IWIMS), tailored specifically for military operations. The Air Force carries over approximately 9.3 billion dollars of maintenance and repair backlog each year, which amounts to 3.5 percent of its current replacement value (CRV) [10]. This quantity of deferred maintenance and repair is above the recommended industry standard of one to two percent residual from year to year [10].

Performance Modeling (Air Force) - Performance modeling for the Air Force serves as the primary tool to prioritize maintenance and repair requirements and utilizes an equation with infrastructure metrics to rank order projects. The goal in shaping our maintenance and repair decision is to choose the most economical approach (from a life-cycle standpoint) to answer the question, what should be fixed first? [19] [20] [23]. These tools, in essence, guide decisions that are related to the established strategic vision. Thus, a dependency exists between the performance model tool and the strategic vision to ensure that the measureable components of the tool provide decision-makers with the necessary information to align viable approaches with the strategic vision.

Goals and Policies (*Air Force)* - To align with the strategic vision of providing sustainable installations by using transformational business practices, the Air Force coined "20/20 by 2020" as one of its goals. "20/20 by 2020" aims to reduce both the physical square footage of Air Force infrastructure as well as maintenance and repair costs by 20 percent by the year 2020 [4]. The Energy Independence and Security Act of 2007, which aims to reduce energy usage by 30 percent by the year 2015 and the "20/20 by 2020" goal are specfic, measureable targets that align with the Air Force strategic level vision; however, the advancement of these goals is limited by available funding.

Budget (Air Force) - Currently, the Air Force allocates 2.5 billion dollars annually to maintenance and repair projects [7]. This budget amounts to 0.95 percent of its CRV, which is significantly lower than the recommended industry standard of two to four percent [23]. With limited resources available, the budget provides boundaries (constraints) for selecting alternatives in order to manage assets from a holistic perspective and make the best decisions possible.

Alternative Selection (*Air Force)* - Alternative selection explores options associated with infrastructure assets to determine which approach is in the agency's best interest. Under the operations and maintenance budget, the Air Force examines five potential resolutions of demolish, continue to maintain and repair, construct an asset with capitalization, renovate, or status quo when determining the most advantageous solution [5].

Operational Plan Development (*Air Force)* - The purpose of operational plan development is to examine how the preferred course of action impacts an agency's infrastructure from a second and third order effect perspective. Once an optimal solution is determined, operational plan development considers how to leverage efficiency from infrastructure networks and how the proposed course of action affects other aspects of these assets [3]. Along with addressing how the optimal solution affects current maintenance and repair projects, planning for future endeavors as well as future maintenance and repair projects occurs as a part of operational plan development. Capitalization, known as military construction (MILCON), constructs a new infrastructure asset that improves capability and corrects infrastructure issues. However, MILCON falls under a separate budget with direct congressional oversight and approval; it does not compete with operations and maintenance funds.

Execution (Air Force) – Execution implements the optimal solution to utilize limited resources in the most effective manner in order to optimize the performance of infrastructure assets. In the case of the Air Force, execution involves coordinating the labor and funding to carry out the demolition, maintenance and repair projects, and/or renovation.

Feedback (*Air Force)* - Asset management for the Air Force is an iterative process that requires a feedback loop. The strategic vision, goals, and policies are in constant flux with the continual movement of headquarters staff personnel and commanders. Additionally, the operations and maintenance budget varies from year to year [9]. Thus, Air Force decision-makers examine results and address changes during feedback, prior to beginning the iterative process of asset management again.

KEY FINDINGS

Analysis of the Air Force logical model highlights and emphasizes two key findings. A discontinuity exists between the established strategic vision, goals, and policies and the current performance modeling tool. Hence, decisions regarding maintenance and repair of infrastructure do not reflect or account for the strategic vision, goals, and policies of the Air Force. For example, the "20/20 by 2020" goal aims to reduce both the physical square footage of Air Force infrastructure as well as maintenance and repair costs by 20 percent by the year 2020, and the Energy Independence and Security Act of 2007 aims to reduce energy usage by 30 percent by the year 2015; however the current equation (performance modeling tool) that prioritizes maintenance and repair projects does not account for energy usage or space utilization. The disconnect between these components results in decision-makers selecting an optimal solution based upon either the strategic vision, goals, and policies or the priority equation, but not both. These competing interests, created by this disconnect, lack synergy and cohesiveness.

Additionally, the data and MMS required for strategic level asset management do not align with the data and MMS required for tactical level asset management. Thus, the lack of compatibility and proper communication hinders the flow of data between vertical levels and stifles a streamlined top down, bottom up approach that enables decision-makers to formulate viable courses of action [4]. As a result, each vertical level focuses on the issues and solutions that pertain solely to that level, instead of resolutions that are in the best interest of all levels; ideally, the approaches and alternatives conceived by the decision-makers are in the best interest of all vertical levels (tactical, operational, and strategic) of the Air Force.

FUTURE RESEARCH

Suggested future research for this project involves the development of a physical asset management model and an improved performance modeling tool. The physical asset management model will visualize, construct, and specify the data requirements for each of the strategic components of the asset management process. It will also portray the actual, computer-oriented implementation and demonstrate how objects are digitally implemented [20]. The physical asset management model and data schema will complete the data modeling process. With a fully developed model, the Air Force will have a comprehensive framework and decision-making tool that provides guidance for the asset management process.

Additionally, the discussion of Air Force asset management components highlights the requirement for an improved performance modeling tool that aligns with the strategic vision, goals, and policies of the Air Force to objectively prioritize maintenance and repair projects. The components of the Headquarters Air Force prioritization model, the current performance modeling tool that rank orders maintenance and repair projects, do not measure all of the performance metrics established by Air Force asset management goals and policies. This disconnect results in competing interests and a lack of synergy between the goals and current performance modeling tool. The lack of a cohesive focus between these two components affects the operational plan development and execution of demolition, renovation, and/or maintenance and repair projects; limited resources are not effectively utilized in a manner that aligns with the strategic vision or goals. Thus, an improved performance modeling tool that incorporates the goals and policies of the Air Force is necessary to objectively prioritize maintenance and repair projects across all major commands.

CONCLUSION

The Air Force introduced asset management into the organization to maximize limited resources and to optimize the performance of infrastructure assets [4]. A requirement for a comprehensive asset management model emerged as a result of the culture shift to asset management and its business practices. This paper adapts a strategic asset management model specifically to the Air Force, that establishes an overarching framework for the decision-making process. It also provides explanations of the strategic components of the model and illustrates relationships among these components. The relationships depicted and described represent critical links between the model's components. The decision process ties the goals, planning, and execution to the strategic vision; the strategic vision guides and shapes the entire process and each component of the model.

The purpose of the proposed model is to provide an objective structure for decision-makers to evaluate the impacts and trade-offs of current and future viable approaches and alternatives. The model provides an analytical process and cost-effective strategies through a structured framework for the iterative processes of asset management. The holistic perspective of infrastructure assets that this model affords is relevant to agencies with large infrastructure inventories and limited budgets. Thus, this proposed strategic asset management model is widely applicable to large organizations, such as the military, large corporations, and universities. It also allows these agencies to maximize their scarce resources and optimize the performance of their infrastructure assets.

REFERENCES

[1] Association of Higher Education Facilities Officers. *Asset Lifecycle Model for Total Cost of Ownership Management.* Washington, D.C.: Association of Higher Education Facilities Officers, 2003.

[2] Batini, C., M. Lenzerinim, and S. B. Navathe. A Comparative Analysis of Methodologies for Database Schema Integration. *ACM Computing Surveys*, 1986, 18, 333-364.

[3] Coullahan, R. and C. Siegfried. Facilities Maintenance Using Life Cycle Asset Management. *Facilities Engineering Journal*, 1996.

[4] Culver, Michael. Transforming the CE Enterprise. *Air Force Civil Engineer Magazine*, 2007, 15, 4-12.

[5] Department of Defense. *Identification of the Requirements to Reduce the Backlog of Maintenance and Repair of Defense Facilities.* Washington, D.C.: Department of Defense, 2001.

[6] Department of Defense. *Department of Defense Financial Management Regulation.* DoD 7000.14-R. Washington, D.C.: Department of Defense, 2009.

[7] Department of Defense. *Operation and Maintenance Overview: Fiscal Year 2011.*Washington, D.C.: Department of Defense, 2010.

[8] Eulberg, Del. Managing Air Force Assets. *Air Force Civil Engineer Magazine*, 2008, 16, 5-7.

[9] Government Accountability Office. *Federal Real Property: Progress Made Toward Addressing Problems, but Underlying Obstacles Continue to Hamper Reform.* GAO-07-349. Washington, D.C.: Government Accountability Office, April 2007.

[10] Government Accountability Office. *Continued Management Attention is Needed to Support Installation Facilities and Operations.* GAO-08-502. Washington, D.C.: Government Accountability Office, April 2008.

[11] Gruber, Thomas R. Toward Principles for the Design of Ontologies Used for Knowledge Sharing. *International Journal Human-Computer Studies*, 2005, 43, 907-928.

[12] Headquarters United States Air Force. *Activity Management Smart Book.* Washington, D.C.: Department of the Air Force, 2009.

[13] Longley, Paul A., Mike Goodchild, David J. Maguire, and David W. Rhind. (2nd Edition). *Geographical Information Systems and Science.* West Sussex, England: Wiley & Sons, Ltd., 2005.

[14] Maunsell Project Management Team. *International Infrastructure Management Manual.* New Zealand: NAMS Group Ltd., 2006.

[15] National Research Council. *Stewardship of Federal Facilities.* Washington, D.C.: National Academy Press, 1998.

[16] Office of the Air Force Civil Engineer. *Strategic Plan 2009-2013.*Washington, D.C.: Office of the Air Force Civil Engineer, 2008.

[17] Robinson, C. Paul, Joan B. Woodard, and Samuel G. Varnado. Critical Infrastructure Interlinked and Vulnerable. *Issues in Science and Technology*, 1998, 61-67.

[18] Schofer, Joseph L., Leonard Evans, Michael P. Freeman, Larry L. Galehouse, Samer Madanat, Ali Maher, Sue McNeil, John J. Myers, Robert L. Peskin, and Butch Wlaschin. Research Agenda for Transportation Infrastructure Preservation and Renewal: Conference Report. *Journal of Infrastructure Systems*, 2010, 16, 228-230.

[19] Silverston, Len. *The Data Model Resource Book*, *Volume 1*.New York: Wiley & Sons, Inc., 2001.

[20] Sitzabee, William E., William Rasdorf, Joseph E. Hummer, and High A. Devine. Data Integration of Pavement Markings: A Case in Transportation Asset Management. *Journal of Computing in Civil Engineering*, 2009, 23, 288-293.

[21] Sitzabee, William E. and Harnly, Marie T. Strategic Asset Management Model. Manuscript submitted for publication, 2011.

[22] Thomas, John. Driving CE Transformation with NexGen IT. *Air Force Civil Engineer Magazine*, 2009, 17, 6.

[23] Vanier, D. J. "Asset Management: "A" to "Z"," *Proceedings of the American Public Works Association International Public Works Congress*. 1-16. Philadelphia: American Public Works Association, 2001.

[24] Vanier, D. J. Why Industry Needs Asset Management Tools. *Journal of Computing in Civil Engineering*, 2001, 15, 35-43.

[25] Whitten, Jeffrey L., Lonnie D. Bentley, and Kevin C. Dittman. (4th Edition). *Systems Analysis and Design Methods.* New York: McGraw-Hill, 2004.